A SPECIFIC LOCOMOTION INTERFACE FOR VIRTUAL REALITY

Design of a Wheelchair Type Haptic

Cédric Anthierens, Jean-Luc Impagliazzo, Yves Dupuis
LISMMA EA2336, Supmeca Toulon, Maison des Technologies, Place G Pompidou, F83000 Toulon, France.

Eric Richard
ISEN Toulon, Maison des Technologies, Place G Pompidou, F83000 Toulon, France.

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Abstract: This paper presents a recent advance in Virtual Reality (VR) related to building design or development of public places. It focuses on the design and implementation of a wheelchair type haptic to simulate ease of access and displacement of a disabled person in a wheelchair in public places. A VR platform equipped with this haptic system provides a Virtual Environment (VE) that represents either a street scene or an interior building scene. This VE is useful for architects who want to efficiently design facilities for disabled access during the design phase. The first part of this paper deals with the lack of consideration of disabled access in everyday places and therefore the need to improve facilities, as emphasized by French law. The second part deals with specifications and expected performances of the VR platform, specifically with regard to the requirements of the whole Virtual Environment. The third part focuses on the mechatronic design and explains how each part of the interface works to produce good renderings and a high level of realism with respect to the main goal defined before. The implementation phase and integration of this specific behavioural interface into the VR platform is presented in the fourth part. The last part before the conclusion and perspectives discusses tests and final results obtained from total immersion within two types of simulated interior environment.

1 INTRODUCTION

For a long time we have observed everyday difficulties encountered by disabled persons that could be avoided if the design of private or public places took their handicap into account. Facilities satisfying able bodied or disabled persons can usually be implemented but this solution is not often chosen. For example, too many public places such as restaurants, concert halls and trains are not yet equipped to receive persons who rely on a wheelchair for their mobility. Accessibility to such places is therefore reduced or, in some cases, is impossible.

A recent French law regarding the rights and the opportunities of disabled persons imposes standards to improve accessibility for all on both existing and new buildings. The L.111-7 article of building and house French code states that public or private buildings or facilities, whether inside or outside must be accessible to all and notably to disabled persons regardless of the type of handicap considered.

Our study focuses primarily on a physically disabled wheelchair user. Beyond the simple respect of the building standards in force, it could be interesting for architects to estimate the importance of these standards in use for the end-user. Indeed the difficulties of moving a wheelchair on a banked walkway or to cross a small step between two rooms for example is often not understood or perceived by designers and therefore they do not change their design according to these considerations.

This is the reason why we would like to give architects the possibility to experience a virtual version of a room or exterior space he/she has designed in which he/she can move with a

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wheelchair. This would enable architects and engineers to better understand the interest to design differently by taking into account the mobility difficulties of everybody (Harrison, 2004).

The benefits of this study are numerous because it can help architects and designers by providing a virtual validation of their modelling, but it can also contribute to change standards to be more suitable for the everyday life of wheelchair users.

These improvements could follow different criteria according to the end user point of view such as comfort, security, accessibility. The aim of this is to provide a VE as a useful tool to help designers and architects. This is why our VE highlights the main nuisances and difficulties, which can be felt by a wheelchair user everyday instead of providing a simulator to learn how to move with a wheelchair. Technical requirements are different depending upon the different goals.

Finally, our VE should simulate if it is easy to move within a virtual room equipped with a table, chairs and other potential obstacles. This is a good method to evaluate the accessibility of objects. Moreover, an emergency exit procedure could be simulated and evaluated by criteria such as the evacuation time for example. Finally, accessibility of a stair via a ramp would be taken into account to verify the acceptable slope defined by the building standards.

Our work offers the option to simulate locomotion either with a mechanical wheelchair or electric wheelchair.

2 VIRTUAL ENVIRONMENT SPECIFICATIONS

According to the goals presented above the VE should be able to make the user feel subtle difficulties to move with a wheelchair within the simulated place. Only one user can be immerged at a time in the considered virtual place. Indeed to validate the ease of access of the scene, it is not necessary to create virtual meeting between several users.

To satisfy a good level of realism our VE must be multisensorial, this is why we decided to offer sight, hearing and touch to the user to interact with the VE. The level of realism should be particularly considered to make the user feel the difficulties of moving in a restrictive room for example. The textural graphic rendering of non interactive objects is not a priority in this study. On the other hand we are interested in locomotion, which is the primary task we have to simulate here. Thus we pay particular attention to the type of displacement (forwards, backwards, rotation, linear), the event during motion (shock, bounce, freewheel) and the nature of the ground (soft ground, horizontal or ramped). The difficulties in simulating these are for example related to the lack of own force to move forward on a ramp, the lack of free space to turn or move in a confined place (lift, end of a corridor, between tables in a classroom...), the lack of skill to maitain the desired direction while moving on a banked walkway and so on.

Manoeuvrability is more difficult in an electric wheelchair than in a mechanical wheelchair. However several difficulties depend on the user's skill and his/her available arm force, which is why we will first focus on the mechanical wheelchair, as this is subject to all types of difficulties.

In its framework our Immersive Environment (IE) is similar to other dedicated VR locomotion interfaces such as a walking device, bicycle simulator and so on. Indeed for this type of platform, the immerged user should perceive that he/she moves voluntarily on the spot. The realism, we decided above to focus on difficulties rendering, must be judged all the time by the three chosen senses (sight, hearing and touch). Of the four behavioural primitives (Fuch, 2003) (observe the virtual world, move and interact in the virtual world, and communicate with another in the virtual world) we decided to consider only the first three.

Our contribution points especially to how to provide the feel of moving in the VE by taking into account all the difficulties quoted above. The visual rendering of the virtual scene will be projected simply on a large screen to create a feeling of immersion and to display object with actual size. For our application, head mounted displays are not suitable as they are expensive and make data processing more complex because of the required head tracking. Elsewhere our VE can be displayed on a hemispherical screen with stereo glasses (reality centre type) or in a CAVE (room-sized cubic system with projections on all walls and floor). This last system is about 3 meters wide and long, so the interface design must be as compact as possible and compatible with these dimensions.

As it has been specified above, we wanted to make the user feel the difficulty and energy required to move in constrained environment. It is therefore necessary to design our behavioural interface as a sensorial and driving interface like a haptic. That means the user will interact with the locomotion task through the wheels of our interface. He/she will also perceive a force feedback according to the characteristics of where he/she is within the VE. This interface will be designed as a classical haptic but its force feedbacks could be high and close to the reality contrary to other haptics which provide a low force feedback to simulate the actual force.

In addition to the sensorial feedback supplied via the independent wheels, we wanted to represent a sensorial feedback to simulate a change of orientation (pitch) while moving on a ramp. This feature is not only to increase the realism level but also to force the user to change his/her posture. For example while he/she moves up on a sloping ground, the wheelchair user leans forwards to balance the wheelchair and avoid falling backwards. This constrained position is uncomfortable and more tiring. Standards specify wheelchair access must have a slope less than 5% for a 10 m long ramp or less than 12% for a 50 cm long ramp. We know the exit walkways from some car parks have slopes much steeper than specified in the buildings standards, and that is why it is interesting to enable architects to try this kind of emergency access !

Shocks should be simulated and felt by user, so we decided to represent a virtual shock by a real shock provided by the quick change of pitch with a significant magnitude. Vibrators fixed on each side of the wheelchair give information about the side against which the shock happened. This feature could be interesting to simulate a scenario where a user encounters an obstacle in a narrow corridor for example,. These five actuated subsystems comprise the touch element of our wheelchair type interface.

Of course a 3D visual and a stereo aural rendering enhances the realism of spatial location and events like shocks or other events that are a part of the considered scene independently of the user's motion.

3 MECHATRONICAL DESIGN

We present in this part the design of the mechanical wheelchair interface which will be upgraded later with a joystick to simulate an electric wheelchair with its specific behaviour. The sensorial feedback is the same for both modes of the interface.

3.1 Framework

In order to keep close to reality we decided to base our interface on a real wheelchair (Figure 1a), which has been instrumented and in part redesigned (Figure 1b). The original wheelchair has been fixed on a tubular framework, which supports it and assures a good stability. This framework can be easily taken apart and is then easily transportable. A rotating joint placed a few centimetres in front of the wheel's axle (just below the estimated static centre of gravity) supports the wheelchair and allows it to lean forwards and backwards to simulate shocks and displacements on a sloping ground.

Figure 1a: Original wheelchair used as base.

Figure 1b: CAD model of mechanical framework.

An electrical jack fixed between the framework and a horizontal tube in front of the wheelchair controls this degree of freedom. It is driven by a DC motor supplied by a PWM signal to be controlled in position. An external angular sensor is placed by the side of this joint to measure the pitch orientation of the wheelchair.

The actuator has been sized according to the angular acceleration and velocity experienced by the wheelchair when it moves on a slope (10% max) with maximal speed of 10 km/h (Equation 1)(Figure2).

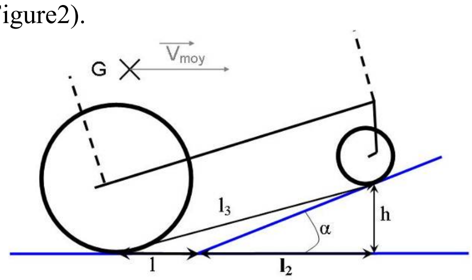


Figure 2: Slope.

With V_{moy}, the initial horizontal velocity, α the angle of the slope, l_3 the wheelbase, h the length to control.

$$\ddot{h}(l_3) = -\frac{v_{moy}^2.\tan\alpha.\sin^2\alpha}{2.l_3}.[1+\frac{\tan^2\alpha}{8}] = 4\,mm.s^{-2}$$

Equation 1

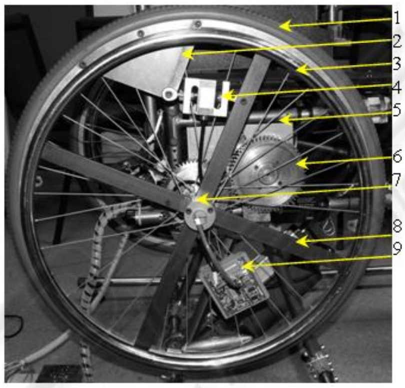
In addition to slopes, shocks to simulate can be provided by lateral contact against walls. However to feel realistic lateral contact should represented by a free motion of the user's legs. Indeed the user's legs behave like seismic mass that undergoes a lateral acceleration or deceleration. To carry out this controlled mobility, it would be necessary to add a yaw degree of freedom, which makes the interface much more complex. In our application, the fine perception of lateral shocks close to reality is not necessary, which is why we decided to use a metaphor to represent them. Vibrators fixed on tubes each side of the wheelchair work and complete the electrical jack to make user feel the side on which the shock happened. Vibrators are based on small DC motors that turn an eccentric for 50 ms. During the implementation phase, vibrators were not judged as necessary because the visual rendering always gave enough information about the contact location. Therefore vibrators were not always used afterwards.

3.2 Wheels

The wheels are certainly the most delicate part to design according to our final goal because they are the main parts for user to interact with and move in the VE as he/she wants. Indeed these parts work in driving mode to control the motion in VE and work also in sensorial to give feedback to user.

As mentioned above, we wanted to make the user feel a force feedback close to the real one to understand difficulty and strenuousness at a real level. The tangential user force applied on the circular handle of the wheel was estimated experimentally at about 150 N. In order to supply a high force (50 N.m torque) during shocks or starts, we could use either a high power motor or an irreversible system. Mechanical implementation (bulk) and control of a high power motor would be delicate at low speed for example, which is why we decided to choose a transmission power chain with a reducing ratio close to the threshold of irreversibility. A 100 Watts DC Motor with a 1:30 reducer ratio was chosen to drive each wheel independently. Each of them is supplied by a PWM signal and drives the gears of the wheel and another gear to drive an incremental encoder. These sensors provide the feedback signals in order to control the direction and velocity of the wheels. Motors and sensors are placed under the seat to maintain the compactness of the wheelchair and to make it easy to link the equipment to the power supply or the main PC.

To get data about the user interaction with the wheels, the joins between handrails and wheels have been instrumented. The force or torque measuring device is very important to provide information about the interaction between the user and the interface. As it is not necessary to measure accurately the actual user's force applied to the handrail, we decided to employ a S-shape force sensor to obtain an image of the tangential force vector. Like that, handrails now equipped with spokes can rotate around the main axle and are fixed on the wheels thanks to the S-shape force sensor (figure 3).



1 : Tire 2 : Force sensor support
3 : Handrail 4 : Force sensor
5 : Motor support 6 : Driving gear
7 : Slipring brush 8 : Circular handle spoke
9 : Sensor electronics

Figure 3: Wheel subsystem.

The wires of the force sensor and its conditioner are placed on the wheel and cross the main axle which is now drilled from tip to tip. The slip-ring brush on the tip axle assures a good connection between the rotating parts and fixed part of wires.

The wheel subsystem provides force data to the Central Unit which computes according to the actual mechanical parameters of virtual environment the theoretical value of the velocity applied on each wheel. This procedure describes the control method used to drive our wheelchair interface as a driving and sensorial interface. With its irreversibility characteristic, this wheel functions as a force feedback joystick. This mechanical particularity can supply a high force feedback when a shock happens. Presently the velocity is controlled by a PID controller, which dynamic enough to simulate shocks (Katsura, 2004). The control law is quite simple because it satisfies well our immersion criteria (difficulties, tiredness). Moreover shocks against walls are not very strong and the virtual wheelchair would not bounce a lot against this kind of obstacle. Finally during a shock, the electrical jack which control the pitch of the interface will be preponderant in comparison with other actuators.

3.3 Data Acquisition

Data from all sensors are collected by a NI Data Acquisition Board PCI 6024E plugged on a dedicated PC. The latter has to control all input / output signals related to the sensors and actuators on the wheelchair.

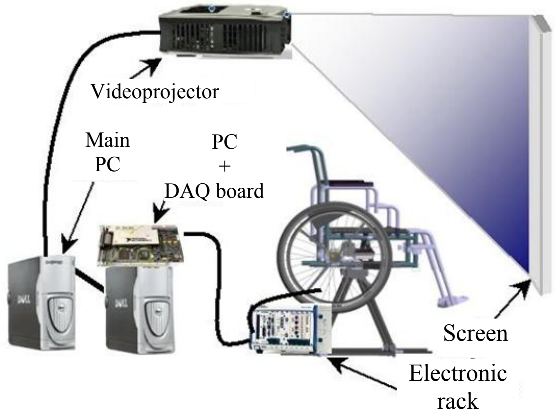


Figure 4: Global architecture.

Input signals are filtered and shaped by an electronic rack before supplying the DAQ board. Figure 4 illustrates the global chosen architecture composed with 2 PCs. The main PC computes the virtual world, receives data from the wheelchair sensors and transmits orders to actuators according to different control laws. This PC has a wider rule to treat the virtual environment which will be detailed below.

Two main power supplies are used to supply firstly the control part (sensors) and secondly the powerful devices such as actuators (wheel motors and electrical jack). For security, an emergency button is placed near the user's left hand to power off all actuators. Those are irreversible and so stop very quickly when power is shut down.

4 MOTION GENERATION

Motion generation is computed by the Virtual Environment Simulator (Flatland) which is presented in the next section.

4.1 Mechanical Behavior

The kinematics and dynamics of our interface are modelled to provide the interface motion by including user's forces, and the reaction of the VE. Indeed the contact between the wheel and ground must be well defined to allow a complete immersion with a good level of realism and so avoid primarily any disturbances or delays between the visual rendering and the touch. Note we want to reproduce the difficulties of motion and this is not limited to experiencing a scene with obstacles and potential shocks. Indeed we wanted to highlight that keeping a desired direction while moving on a banked ground is particularly difficult and need skill and force from the wheelchair user.

That is why the user's forces and effect of the ground on the wheels have been reduced to a dynamic torsor applied on the median point of contact on the ground. Thus by taking into account the mass distribution, the nature of contact between wheel and ground, and external actions from user and ground, we modeled a banking torque which disturbs the direction of motion. Also the difficulties involved in a simulating banked ground are rendered not by roll change of wheelchair interface but by disturbing the motion direction and via a disturbing torque applied differently to each wheel. In freewheel on banked ground, the wheelchair, under the banking torque action, tends to be oriented in the direction of the bank and so it can swing around this direction if it started from an unspecified orientation.

4.2 Joystick Behavior

A joystick driving mode is necessary to simulate the behavior of an electric wheelchair in a VE. As for the mechanical model, a dedicated model has been proposed to simulate the joystick functioning and the whole electric wheelchair control unit.

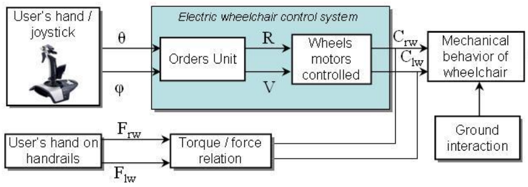


Figure 5: Architecture of electric wheelchair.

With φ and θ angles of both joystick's dof, R and V respectively the curve radius and the velocity of the desired trajectory, Crw and Clw respectively torques on right and left wheels, Frw and Flw respectively forces on right and left wheels.

The mechanical behavior of the wheelchair is supplied either by joystick data or user's force data depending upon whether the electrical mode or mechanical mode was chosen (figure 5).

Both modes of control simulate the actual behaviors well and are implemented in the VE as described just below.

5 IMPLEMENTATION

The VE runs in Flatland which is a simulator of virtual world created and developed by LISMMA laboratory (Yushchenko, 2003). This simulator is designed to be connected to all kinds of behavioral interface like haptics or locomotion interfaces for VR (Dupuis, 2005). Flatland uses Parallel Virtual Machine libraries to distribute computations on the PC cluster. The main PC presented above runs Flatland and controls another PC that tracks eye movement. This architecture is interesting to compute heavy tasks such as that which controls the video rendering.

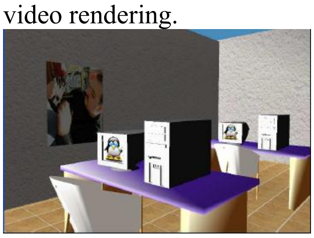


Figure 6a: A virtual room.

Figure 6b: Electric wheelchair mode.

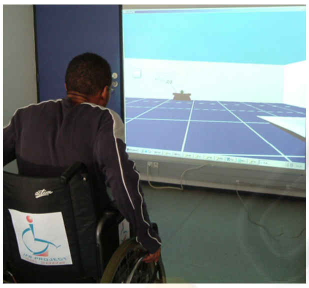


Figure 6c: Mechanic wheelchair mode.

Different types of environment can be implemented for example like a classroom (figure 6a) or a hall equipped with wheelchair access (figure 6c). All VEs can be explored virtually with any modes of functioning (figure 6b).

Many experiments have been carried out to evaluate the degree of realism. Globally, it appears that the wheelchair interface is very intuitive and natural. Indeed the user's action are similar than those he/she would do in actual reality. Sensorial feedbacks are immediately understood by the user and so he/she can focus on the main task, which is to move as he/she wants.

Furthermore, the difficulty and energy required to move is simulated well because the motion within a virtual room is felt as a real effort when the interface is used in mechanic wheelchair mode.

A virtual corridor is useful to evaluate the user's skill and difficulties in building design while the interface was controlled as an electric wheelchair.

6 CONCLUSION

The work presented here, widely supported by SMI/MIT students from Supmeca and ISEN institutes, achieves its original goals in order to help building designers in their task.

The locomotion interface wheelchair-type we have designed is effective in highlighting the difficulties which can be experienced by disabled wheelchair users. Mechanical and electric wheelchairs were implemented and both correctly simulate the actual behaviour. This study illustrates the great interest of the generic interface feature in order to connect any kind of locomotion interface to Flatland.

The next step of this research is to implement a spatial sound feedback to upgrade our present stereo rendering. Indeed within a noisy hall or close to a train in a station for example, noise can easily be considered as a lack of comfort or more a hindrance to catch information.

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